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Image blur resulting from dispersion in polycarbonate

Abstract

Visual acuities were measured through a series of prisms in order to quantify the blur that results from dispersion in polycarbonate. The mean VA of forty eyes declined from 20/13 unaided to 20/31 through 16 prism diopters of polycarbonate. The decline was a linear function of prismatic power. The blurring effect of polycarbonate was significantly greater than that of CR39. The blur from polycarbonate was found to be great enough that it should be taken into account whenever polycarbonate is considered for spectacle lenses. Graphical displays are provided which can be used by the clinician to predict the degree of blur from a known polycarbonate lens.

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Niles Roth

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IMAGE BLUR RESULTING FROM DISPERSION IN POLYCARBONATE

A Thesis Presented to Pacific University College of Optometry
for the Degree
Master of Science
in
Clinical Optometric Management

by

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March 1990

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The conclusions and assertions contained herein are the private views of the author and are not to be construed as the official views of the Department of the Army or the Department of Defense.

Dedication

There's no way I could do this myself, without you.
You're my guide and my counsel, encouragement, too.
Dear wife Sondra, I thank you for starting me up
And for keeping me going, for seeing me through.

ACKNOWLEDGEMENTS

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ABSTRACT

Visual acuities were measured through a series of prisms in order to quantify the blur that results from dispersion in polycarbonate. The mean VA of forty eyes declined from 20/13 unaided to 20/31 through 16 prism diopters of polycarbonate. The decline was a linear function of prismatic power. The blurring effect of polycarbonate was significantly greater than that of CR39. The blur from polycarbonate was found to be great enough that it should be taken into account whenever polycarbonate is considered for spectacle lenses. Graphical displays are provided which can be used by the clinician to predict the degree of blur from a known polycarbonate lens.

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INTRODUCTION

The extremely high impact resistance of polycarbonate is well known.[1] It has been widely used for several years in helmets, shields, nonprescription protective glasses, and other safety applications. Possessing additional advantages of light weight, ultraviolet absorption, and high index of refraction, it is increasingly being used for prescription ophthalmic lenses.

Recent litigation results make it clear that the prescriber, dispenser, and manufacturer of ophthalmic goods are all legally obligated to recommend the safest spectacle materials to the patient. The impact resistance advantages of polycarbonate have led to its recommendation as the lens material of choice in circumstances of significant risk, such as in industry and with sports, children, and monocular patients. This is urged by legal authorities in optometry and by the optical industry as well.[2–7] The polycarbonate share of the U.S. ophthalmic lens market, presently approximately six percent,[a] is likely to increase because of this liability.

A drawback, however, is the relatively high dispersion of polycarbonate. This characteristic, also known as **constringence**, can lead to color fringes and loss of image clarity in the periphery of prescription lenses. As it is a function of prismatic power, the effect increases with stronger lenses and increased eccentricity of gaze. Patients have been known to reject polycarbonate lenses for this reason.[8,9]

But *how much* blur does it cause? Although it is generally known that polycarbonate causes significant dispersion, practitioners lack quantitative information on the resultant blur. It would be useful to prescribers to know how much the visual acuity could be expected to decline for a known lens power and eccentricity of gaze. Patient counseling could then be made more specific, less vague. Dr. Smith could tell Mrs. Jones, "With your prescription, if you look this far from the center of your

lenses, your vision clarity will be reduced to this level." The doctor could use a Snellen chart to demonstrate the predicted loss of acuity, and could determine whether the blur was acceptable to the patient and compatible with the patient's visual needs.

The purpose of this paper is to provide that quantitative information. This study measured the degradation of visual acuity (VA) as it relates to prismatic power. The question asked was this: "How much does VA decline for a given prism power, and is that decline statistically and clinically significant?" The effect of ophthalmic lens materials of high dispersive power, polycarbonate, and low dispersive power, CR39, were studied and compared against each other.

The measure of a material's dispersion is the coefficient of mean dispersion (the nu value, or **v**, also referred to as the Abbe number). It is calculated by the following formula:[10]

$$v = \frac{n_e - 1}{n_{F'} - n_{C'}}$$

In this formula, n_e is the refractive index for mercury green (546.1 nm), $n_{F'}$ is the refractive index for cadmium blue (480.0 nm), and $n_{C'}$ is the refractive index for cadmium red (643.8 nm). The refractive index for short wavelengths (blue) is greater than that for long wavelengths (red).

With a relatively small difference between the indices of refraction at the two extremes of the visible spectrum, i.e. with low dispersion, the denominator in the formula will be small and v will be a relatively large number. Conversely, with a larger difference between the indices at the red and blue ends of the spectrum, i.e. with high dispersion, the denominator will be larger and v will be a relatively small number. In other words, v is an inverse function of dispersion; the greater the tendency of a

material to disperse white light into its spectral components, the lower will be its coefficient of mean dispersion (v).

Polycarbonate has a v value of 30.[8,9,11] The v of crown glass and CR39 are essentially equal; v(CR39) is 58 and v(crown glass) is 58.8.[10]

The **chromatic power** (CP) is a means of describing the dispersion of a specific prism.[12]

$$CP = \frac{\text{prismatic effect}}{v}$$

The chromatic power of a material increases as v decreases and as the prismatic effect increases. Thus, since v of polycarbonate is half that of crown glass and CR39, its chromatic power is twice that of crown glass and CR39 for a given amount of prism.

The dispersive power of polycarbonate was considered in the design of the Gentex polycarbonate lens series.[13,14] No claim was made that the high dispersion could be overcome, rather that the resultant blur made it imperative that the lens design must minimize other errors. Concern for this problem led to the manufacturer's recommendation for extra care in surfacing (base curve selection is critical) and in the fitting of polycarbonate lenses.[15]

The effect of dispersion on visual acuity has been studied by Meslin and Obrecht.[12] Using plano prisms of various materials, they established a series of increasing chromatic powers through which they measured visual acuities. Though they found that dispersion had a significant effect on visual acuity, their conclusions were that it should not preclude the use of high constringence materials for spectacle lenses. Since visual acuity is not an interval scale, the standard statistical manipulations of the decimal acuity data in that study are questionable.[15] In no way does that invalidate the study, however, and the present experiment pursues a similar method.

METHODOLOGY

We chose to use prisms rather than prescription ophthalmic lenses for several reasons. Most importantly, it is a means by which the oblique aberrations of coma, oblique astigmatism, and distortion can be excluded, along with lens design characteristics. Those will vary in degree depending on the angle of gaze through the lens and the design of the lens, and are not characteristics which are being studied here. With the use of prisms, chromatic dispersion is isolated as the optical characteristic which distinguishes the two materials.

A major regional supplier of polycarbonate spectacle lenses fabricated two sets of plano prisms for this study, one set of polycarbonate and one set of CR39. Each set consisted of eight prisms of these powers: 2, 4, 6, 8,10,12,14, and 16 prism diopters. This produced a graduated series of prisms of high constringence (polycarbonate, v=30) and a matching series of prisms of low constringence (CR39, v=58), sixteen prisms all together. (The true powers varied from the stated power by 1/2 prism diopter in five prisms. The 14 and 16 diopter polycarbonate prisms were measured at 13.5 and 15.5 prism diopters respectively. The 6, 14, and 16 diopter CR39 prisms were actually 6.5, 14.5, and 16.5 diopters respectively.)

The experimental population consisted of 40 essentially emmetropic eyes, the selection criterion being 20/20 (6/6) or better uncorrected visual acuity. Two subjects had only one qualifying eye; there were 21 subjects altogether, 14 males and 7 females. Subjects were students, faculty members, and family members of students and faculty at Pacific University, Forest Grove, OR. All subjects were volunteers. Their ages ranged from 24 to 63 years.

Visual acuity was measured for each subject eye in the unaided state and through each of the sixteen prisms, seventeen measures in all. The prisms were placed before the tested eye in the back cell of a trial frame. The contralateral eye was occluded by an

opaque disk, also in the rear-most cell. The laboratory edged the prisms so that the trial lens ring was at the posterior (ocular) surface; all ocular surfaces were therefore normal to the visual axis when the prisms were placed into the trial frame. No additional corrective trial lenses were used, hence there were no multiple lens surfaces to present a confounding variable in VA testing.

We modified a first-generation Baylor Visual Acuity Tester (BVAT) to produce optotype size increments of 2 1/2 feet (Snellen), equal to one eighth of a minute of arc. This permitted very small changes of optotype size and consequently fine measurements of VA. For example, between the visual acuities 20/10 and 20/20 were the following values: 20/10 (.5 min.), 20/12.5 (.625 min.), 20/15 (.75 min.), 20/17.5 (.875 min.) and 20/20 (1.0 min.).

The experimenter tested the subject's right eye first, starting with unaided VA. The prisms were then placed in the trial frame in random sequence, and the VA was measured through each. The left eye was then tested in the same manner.

Letters were used as the testing optotypes. The psychophysical technique used in data gathering was an adaptation of the method of limits. Three runs, starting alternately above and below threshold, were conducted under each of the seventeen conditions (unaided and each prism value). Each run consisted of a sequence of increasingly larger (if below threshold) or increasingly smaller (if above threshold) presentations of five test letters. The letters were randomly changed upon each presentation. The end point value was the smallest optotype size which was identified 80% (four of five) correctly. The three end point values were converted from visual acuity notation into minutes of arc and averaged to produce that subject eye's minimum angle of resolution (MAR) for each of the seventeen testing conditions. MAR means were then calculated for the entire experimental group.

The BVAT monitor screen was produced by Motorola, model number M3560-155, incorporating the P4 phosphor. The monitor was masked by an off-white

shield with an aperture within which the letters were centered. The testing distance was six meters. Ambient room illumination was 172 lux (16 foot-candles) as measured by the Spectra *Candela* ^{TM} meter (Photo Research). Optotype/screen contrast was 98%, as measured by a J16 digital photometer and a J6523-2 narrow-angle luminance probe (both by Tektronix). The monitor screen background luminance mean was 292 c/m^2 (nits), as measured by the same Tektronix instruments. Screen luminances were measured at the top, right, bottom, and left edges of the exposed portion of the screen, and all findings were within 14% of the mean.

RESULTS

The MAR increased with increasing prismatic power for both polycarbonate and CR39. The degree of the effect, equivalent to a decline in VA, was much greater with polycarbonate. Mean MAR's are presented in Table 1. They are graphically depicted in Figure 1.

The mean unaided MAR was 0.66 minutes of arc, equal to a visual acuity of 20/13.2. Through both materials the mean MAR increase (VA decline) was fairly linear, reaching 1.56 minutes of arc, or 20/31.2, through 16 prism diopters of polycarbonate. This was a MAR increase of 0.90 minutes over the unaided MAR. Through 16 prism diopters of CR39 the mean MAR was 1.04 minutes, or 20/20.8, an increase of 0.38 minutes over the unaided mean.

Unaided MAR's ranged from 0.42 minutes (20/8.4) to 0.92 minutes (20/18.4). Similarly, subjects varied in the degree to which their vision was affected by the prisms. Through polycarbonate, the greatest MAR differential between unaided and 16 prism diopters was 1.79 minutes; the least was 0.50 minutes. Through CR39, the greatest MAR increase was 0.91 minutes and the least was 0.08 minutes.

Three separate one-factor analyses of variance (ANOVA) for repeated measures were performed. The first judged the significance of the effect of polycarbonate on MAR. The ANOVA made comparisons between the mean unaided MAR and the mean MAR at each prism value increment of the polycarbonate series. With the exception of unaided v. 2 prism diopters, all comparisons showed strong statistical significance as assessed by the Scheffé F-test. By design, this test describes significance at the 90% level.

The second ANOVA assessed the significance of the effect of CR39 on MAR. It made comparisons between the mean unaided MAR and the mean MAR at each step of the CR39

	UNAIDED	POLYCARBONATE							
		2Δ	4Δ	6Δ	8Δ	10Δ	12Δ	14Δ	16Δ
MEAN	0.66	0.74	0.81	0.92	1.05	1.17	1.31	1.49	1.56
S.D.	0.11	0.14	0.15	0.23	0.26	0.28	0.29	0.32	0.30
		CR39							
		2Δ	4Δ	6Δ	8Δ	10Δ	12Δ	14Δ	16Δ
MEAN		0.68	0.68	0.70	0.75	0.82	0.87	0.95	1.04
S.D.		0.12	0.11	0.12	0.15	0.20	0.20	0.20	0.27

TABLE 1. MEAN MINIMUM ANGLES OF RESOLUTION (M.A.R.) N=40
(Minutes of arc)

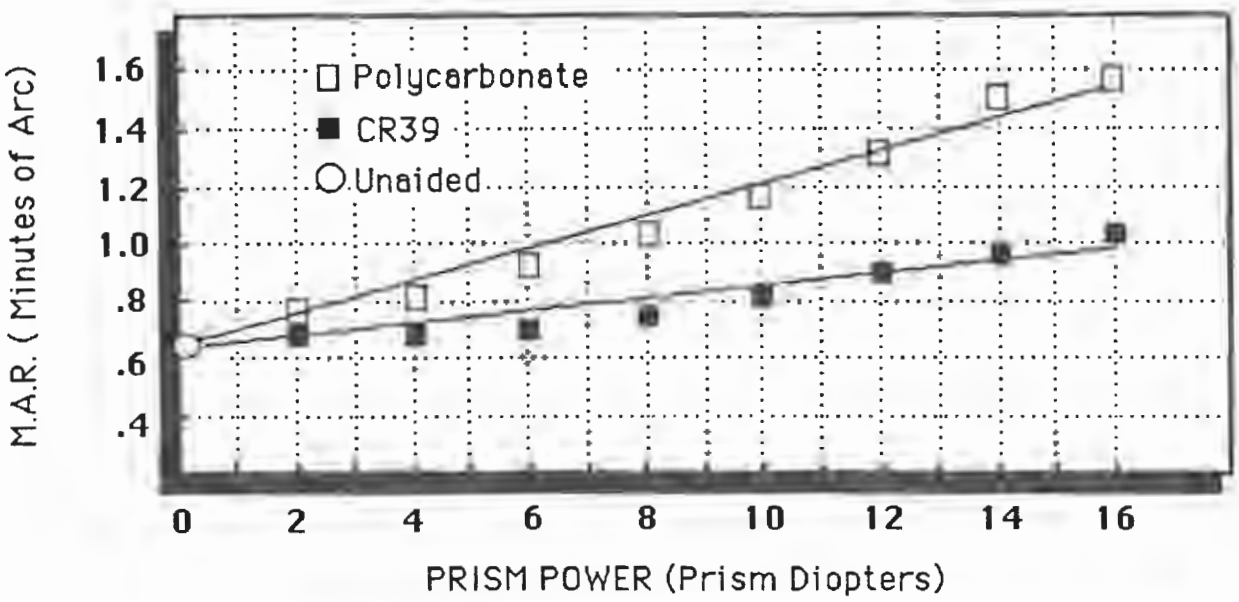


FIGURE 1. MINIMUM ANGLE OF RESOLUTION (M.A.R.) as a FUNCTION of POLYCARBONATE and CR39 PRISM POWER

series. In that case, there was no statistical significance at the unaided v. 2, 4 and 6 prism diopter levels. Unaided v. 8, 10, 12, 14, and 16 prism diopters were significant.

The third ANOVA compared the polycarbonate and CR39 slopes. It answered this question: was the effect of polycarbonate on mean MAR significantly different than the effect of CR39 on mean MAR? In order to do this the algebraic difference between mean MAR values for polycarbonate and CR39 at each increment on the prism diopter scale was calculated. The ANOVA then compared each such difference against that same finding at all other points on the scale. (For example, at 4 prism diopters the MAR means were 0.81 min. for polycarbonate and 0.68 min. for CR39, a difference of 0.13 min. This was compared to differences of .06 min. at 2 prism diopters, .22 min. at 6 prism diopters, and other values at the other prism diopter increments.) This analysis determined that there was no significant difference between $MAR_{poly} - MAR_{CR39}$ differences at any two adjacent points on the prism diopter scale. When mean MAR differences at non-adjacent points were compared, however, they differed with strong statistical significance.

DISCUSSION

These results show that image quality is reduced by prisms made of polycarbonate and of CR39, and that polycarbonate causes the greater degree of blur. Prismatic distortion[17] being equal between the two materials at any given prism power, differences can be attributed to chromatic aberration. The blurring effect of polycarbonate, as measured by changes in the minimum angle of resolution, is statistically significant in all prisms of 4 diopters and greater. The blurring effect of CR39, on the other hand, is statistically significant only in prisms of 8 prism diopters and stronger. There is strong statistical significance to the difference between the polycarbonate and CR39 effects.

The small power errors in the experimental prisms may slightly reduce the apparent difference between the two materials. The 14 and 16 diopter polycarbonate prisms were both 1/2 diopter weaker than stated. If the findings are affected at all by this small error, it can be presumed that the dispersion and resultant blur found at those points on the polycarbonate scale are slightly less than if the prisms had been of full stated strength. Likewise the 6, 14, and 16 diopter CR39 prisms were each 1/2 prism diopter stronger than stated. This would cause the blur measured at those points on the CR39 scale to be slightly greater than if the prisms were at their stated power. The differences between the blur effects of polycarbonate and CR39, therefore, may be understated to a small degree by this analysis.

The issue of *clinical* significance, of course, has greatest meaning to the practitioner. The dominant prescription lens materials, CR39 and crown glass, share the same low coefficient of dispersion, and their peripheral effects are familiar to practitioners and patients. Whatever small degree of clarity is lost due to dispersion or other aberrations in the lens periphery is accepted as the norm. Any increase from that may be noticed and may become distracting to the patient. If that occurs, or if vision

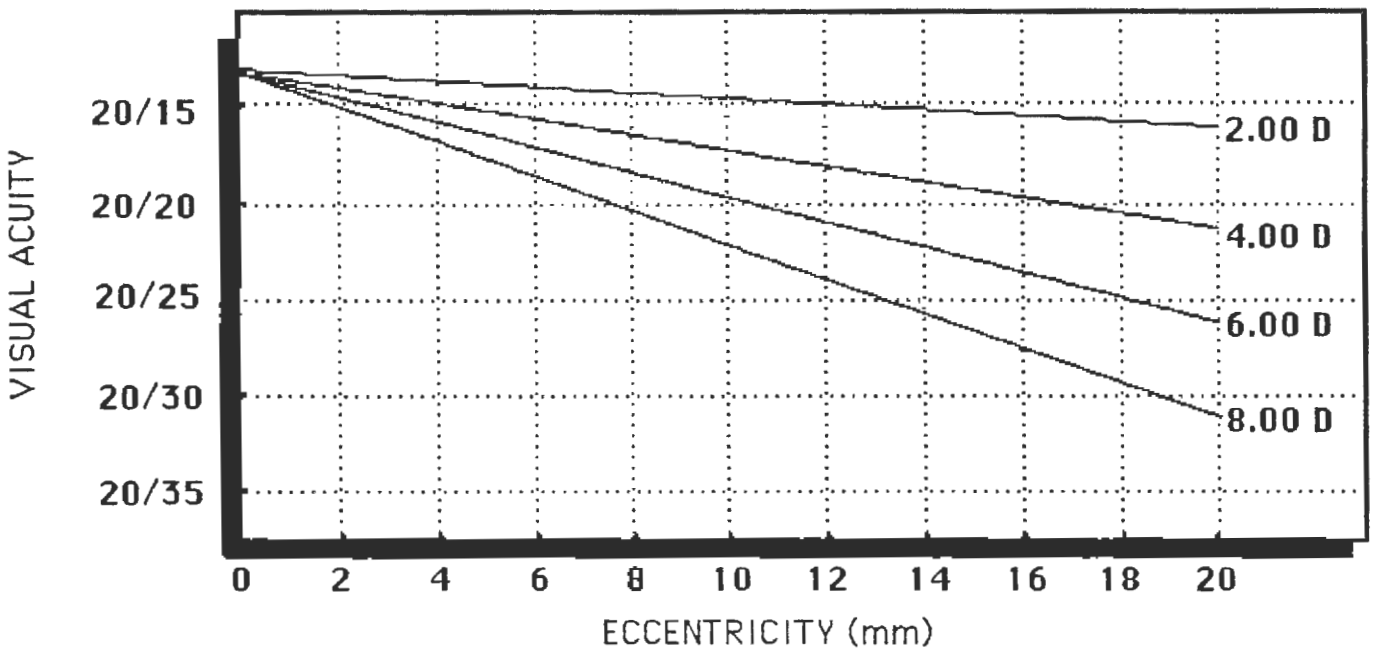


FIGURE 2. VISUAL ACUITY as a FUNCTION of ECCENTRICITY of GAZE for VARIOUS POLYCARBONATE LENS POWERS (20/13 BASELINE).

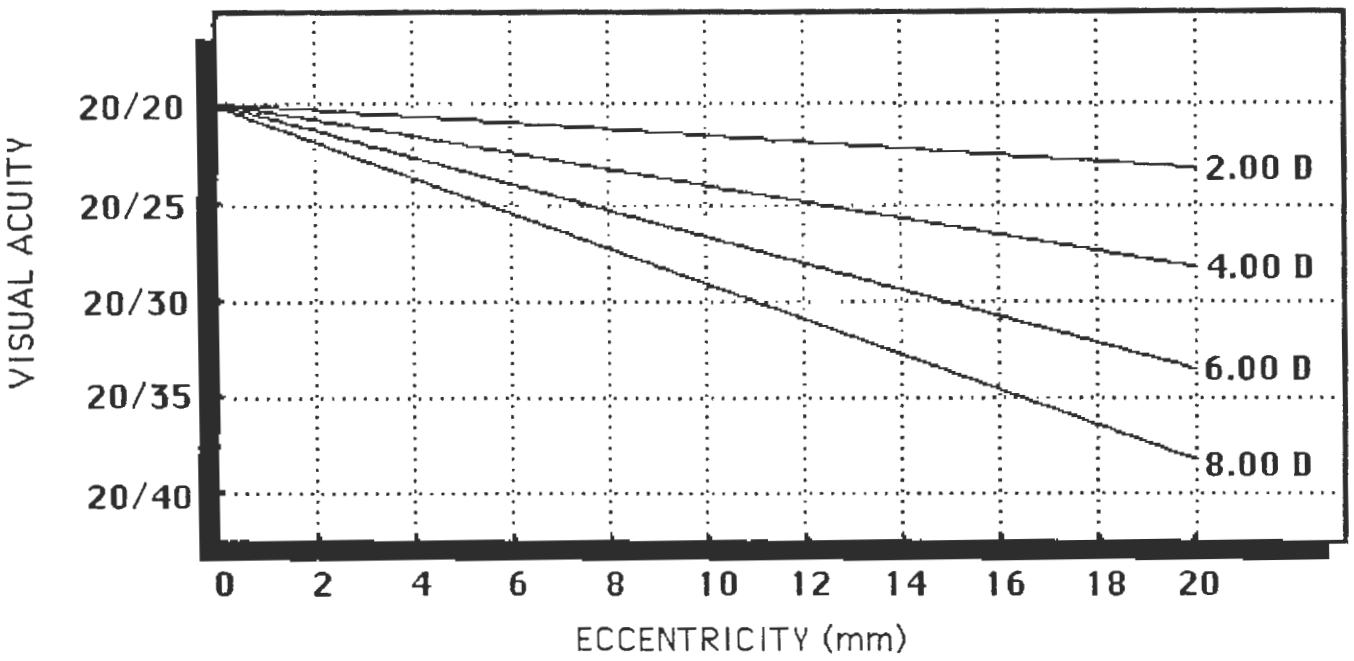


FIGURE 3. VISUAL ACUITY as a FUNCTION OF ECCENTRICITY of GAZE for VARIOUS POLYCARBONATE LENS POWERS (20/20 BASELINE).

clarity is disturbed enough to interfere with function, then the blurring effect of polycarbonate's higher constringence becomes clinically very relevant.

Figures 2 and 3 can be used in the clinical application of the data. Polycarbonate MAR's are converted into Snellen fraction notation. Prismatic effect is converted into dioptric power and distance from the center of a prescription lens by use of Prentice's Law[18]. The slopes are fitted by eye. The slopes depict the visual acuities which will be achieved through polycarbonate lenses of 2.00, 4.00, 6.00, and 8.00 diopters out to 20 mm from the center.

Figure 2 is based on best visual acuity of 20/13, the same as the baseline mean VA in this study. Using the example of a 4.00 D polycarbonate lens, if the line of sight passes through the lens 20 mm from the center, the resultant VA will be approximately 20/21. If an 8.00 D lens is used (about the maximum meridional power available in finished lens blanks from polycarbonate lens manufacturers), also at 20 mm from the center, the VA will be approximately 20/31.

This study's baseline mean VA of 20/13, however, was measured under ideal laboratory conditions with high-resolution optotypes. Accordingly, it is somewhat better than the average best VA that can be expected in the clinic. If the assumption is made that the blur effect is fairly consistent within a limited range of baseline VA's, then the predicted acuity decrement can be applied to any VA within that range. Figure 3 displays the same slopes as Figure 2 but is based on a starting acuity of 20/20. Using this starting point, a 4.00 D polycarbonate lens at 20 mm from the center yields VA of 20/28 and an 8.00 lens at 20 mm from the center yields 20/38.

Figure 4 presents the acuity decrement for both materials in the form of changes in the Snellen denominator. Again, the blur effect is considered a constant within that reasonably narrow "normal acuity" range. The ordinate scale is derived from the following linear relationship between the denominator of the Snellen visual acuity fraction and the Minimum Angle of Resolution: Snellen denominator = MAR X 20. (This

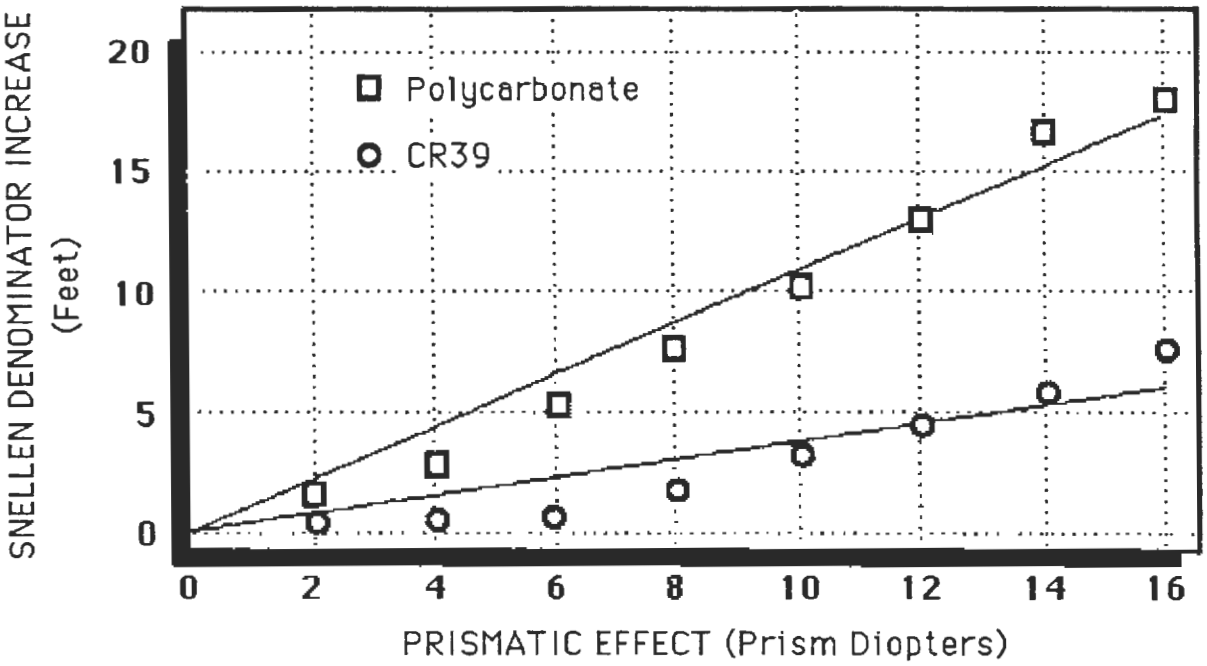


FIGURE 4. INCREASE in SNELLEN DENOMINATOR as a FUNCTION of PRISMATIC EFFECT with POLYCARBONATE and CR39

assumes the 20 foot Snellen standard; e.g. MAR 1.0 minutes of arc is 20/20, MAR 2.0 minutes is 20/40.) Hence, an MAR increase resulting from dispersion blur converts directly into an increase in the Snellen fraction denominator. The original data is plotted in that form in Figure 4 and a best-fit line is added. Using this slope and using Prentice's Law to calculate prismatic effect, the VA decrement at virtually any point on a prescription polycarbonate lens can be predicted. Adding that decrement to the best VA yields the estimated VA through that part of the lens.

For example, at 20 mm. from the center of a 4.00 diopter lens there are 8 diopters of prismatic effect. Figure 4 indicates that 8 diopters of prismatic effect in a polycarbonate lens will increase the Snellen denominator by approximately 8 feet, decreasing 20/20 visual acuity to 20/28. The same amount of prism in CR39 will cause 20/20 to decrease only to 20/23.

The visual acuity changes indicated by these best-fit prediction lines are estimates. And, as the experimental findings clearly show, the blur response varies between individuals. Likewise, illumination varies in the real world. The background illumination provided by the BVAT's P4 phosphor was somewhat grayish, in the manner of an overcast sky. The spectral energy characteristics of other types of illumination (e.g. fluorescent lighting, or daylight at noon under a blue sky) are different, and color fringes from dispersion will be affected to some degree by those differences.

The predicted VA's are best described as optimistic, or "best-case" estimates. They represent the level to which visual acuity is reduced by the effect of dispersion (and, to some degree, prismatic distortion). As discussed previously, the use of prisms in this study permitted us to avoid the aberrations present in the periphery of prescription lenses, isolating dispersion as the investigated variable. In clinical practice, those aggravating factors will be present in varying degree depending on the prescription and the lens design. In whatever degree they exist, they will add to the degradation of image quality. Visual acuities through the periphery of prescription

polycarbonate lenses, therefore, can be expected to be no better, and probably somewhat less, than those predicted by Figures 2 - 4.

These questions arise: "Even if there is greater blur in the periphery of polycarbonate lenses, just how important is that? Is it not true that the average person turns the head rather than turning just the eyes, so that fixation is as much as possible in the straight-ahead position?" Authors disagree on the issue. Adler[19] states that the eyes rotate 30° laterally, 60° to 75° down, and 20° to 30° up "before the head is moved." At a vertex distance of 15 mm with 10° pantoscopic tilt, those angles of gaze equal 9 mm laterally, 20 to 34 mm down, and 6 to 10 mm up. In a study of head and eye movement responses to peripheral signals, Bartz[20] found that few head movements were made in response to stimuli less peripheral than 40°. That angle is equal to 13 mm of eccentricity. In apparent disagreement, Gresty[21] determined that when subjects were instructed to fixate continuously presented targets at an angle of 14.7°, they always moved their heads, though there was head movement less than half the time when they fixated targets at that same angle that were presented only briefly. At the lens, 14.7° translates to 4 mm from the straight forward position of gaze. Afanador and Aitsebaomo[22] investigated the range of eye movements at near, using as their criterion less than a two degree compensatory head movement. Their study showed a total range, to the left *and* right, of less than 14° (less than 4 mm). Bartz[20] further determined that head movement in response to a flashed peripheral target was not initiated by foveal fixation of that target, and that fixation was not achieved until head movement was complete, at which time the angle of turn of the eyes was very small. In other words, no foveal fixation occurred until the head was pointed toward the object of regard.

With the exception of Adler's measure of the depression of gaze for reading, all agree that the average person does not commonly fixate at extreme angles which require looking through the far lens periphery. It is reasonable to expect that some persons will rotate the eyes more, some less, and that the nature of the visual task is a factor (for

example a brief glance, as with using the rear view mirror while driving, versus careful fixation with the need for resolving fine detail). With low-power lenses and unremarkable visual needs there may be no detectable blur or even any persistent color fringes.

But even though steady fixation through the lens edge is not regularly expected, personal and clinical experience tell us that clear vision in the periphery of spectacle lenses is desirable. Loss of peripheral clarity may be distracting and annoying, especially in vocational or recreational circumstances which preclude fixation through the center of the lens. To the golfer addressing a putt, clear vision through the lens periphery is desirable since the head is not easily rotated to fixate the cup while the body is in that position. In some cases peripheral blur could be a handicap. It is not difficult to imagine vision-critical industrial situations in which maximum clarity out to the edges of the lens is essential for reasons of safety as well as job performance. In the military scenario, consider the infantryman aiming at a target with his cheekbone pressed against the stock of his rifle, or the jet fighter pilot craning his neck to search the sky for aircraft approaching from behind.

Clearly, these are not visual requirements encountered with every patient. The degree of VA loss found here, however, suggests that the prescriber would be prudent to consider whether the off-center blur of polycarbonate possibly creates a functional or safety disadvantage that equals or exceeds its impact resistance advantages.

The conclusions from this study are that in certain combinations of prescription power and eccentricity of gaze there will be significant blurring of vision due to the dispersion inherent in polycarbonate. The loss of image sharpness is great enough that it should be considered in the selection of lens materials. The reader can use Figures 2 - 4 to predict the degree of visual acuity which will be lost due to dispersion when looking through the periphery of a known polycarbonate lens.

FOOTNOTES

[a] Personal communication with Mr. Gene Keeney, Optical Manufacturers Association (OMA), 26 January 1990. The 1989 ophthalmic lens market shares were the following: CR39 73%, glass 21%, and polycarbonate 6%. The OMA predicts that the polycarbonate share will begin to increase dramatically due to product liability concerns on the part of major optical chains and optical "superstores".

References

1. Davis JK. Perspectives on impact resistance and polycarbonate lenses. Int Ophthalmol Clin 1988 Fall; 28(3):215-218.
2. Classé JG. Clinicolegal aspects of practice. South J Optom 1986 Apr; IV(2):36-43.
3. Classé JG. Legal aspects of prescribing for athletes and sportsmen. J Am Optom Assoc 1987 Aug; 58(8):674-679.
4. Classé JG. Legal aspects of sports-related ocular injuries. Int Ophthalmol Clin 1988 Fall; 28(3):211-214.
5. Classé JG, Scholles J. Liability for ophthalmic materials. J Am Optom Assoc 1986 Jun; 57(6):470-477.
6. Woods TA. The role of opticianry in preventing ocular injuries. Int Ophthalmol Clin 1988 Fall; 28(3):251-254.
7. Anonymous. Duty to warn. Information pamphlet, Optical Lab Assoc 1987.
8. Jalie M. Use, and abuse, of high refractive index media. Optician 1987 Nov 20; 194(5124):16-20.
9. Merigold PA. Developments in glass materials. Aust J Optom 1982 May; 65(3):107-115.
10. Meyer-Arendt J. Introduction to classical and modern optics, 3rd ed. Englewood Cliffs, NJ: Prentice-Hall, 1989.
11. Davey JB. 'Slimline': CPL adds high index range. Ophthalmic Optician 1983 May 7; 23(10):318-321.
12. Meslin D, Obrecht G. Effect of chromatic dispersion of a lens on visual acuity. Am J Optom Physiol Opt 1988 Jan; 65(1):25-28.
13. Davis JK. A polycarbonate ophthalmic-prescription lens series. Am J Optom Physiol Opt 1978 Aug; 55(8):543-552.
14. Anonymous. Optical guide to polycarbonate performance. Product information brochure, Gentex Corp 1987.
15. Anonymous. The Gentex lens series; custom design for the patient. Product information brochure, Gentex Corp 1987.
16. Halldén U. Notes on the statistical treatment of the visual resolution. Acta Ophthalmol 1972; 50:47-57.
17. Ogle, KN. Researches in binocular vision. Philadelphia: W.B. Saunders, 1950.
18. Cline D, Hofstetter HW, Griffin JR. Dictionary of visual science, third ed. Radnor, PA: Chilton, 1980.
19. Adler FH. Physiology of the eye, fourth ed. St. Louis: C.V. Mosby, 1965.

20. Bartz AE. Eye and head movements in peripheral vision: nature of compensatory eye movements. Science 1966 Jun 17; 152(3729):1644-1645.
21. Gresty MA. Coordination of head and eye movements to fixate continuous and intermittent targets. Vis Res 1974; 14:395-403.
22. Afanador AJ, Aitsebaomo P. The range of eye movements through progressive multifocals. Optom Month 1982 Feb; 73(2):82-87.

APPENDIX A

Measurement of Luminance and Contrast

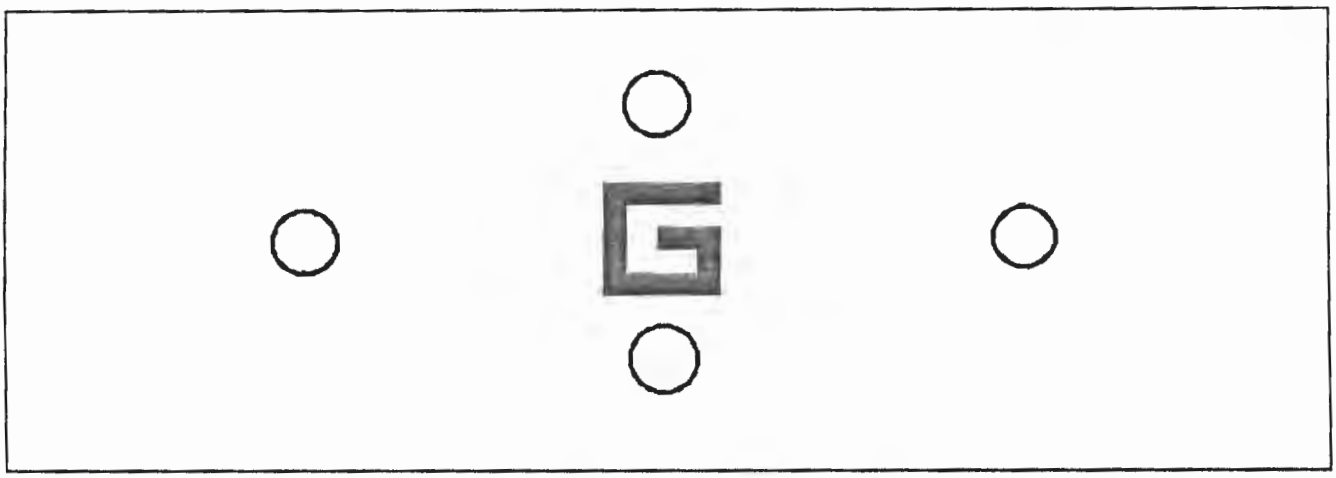


Diagram of the Aperture Through Which the Subject Viewed the Screen of the Baylor Visual Acuity Tester. (The four circles represent the four locations at which the screen luminance was measured. A 20/25 optotype was centered on the screen when the measurements were made.)

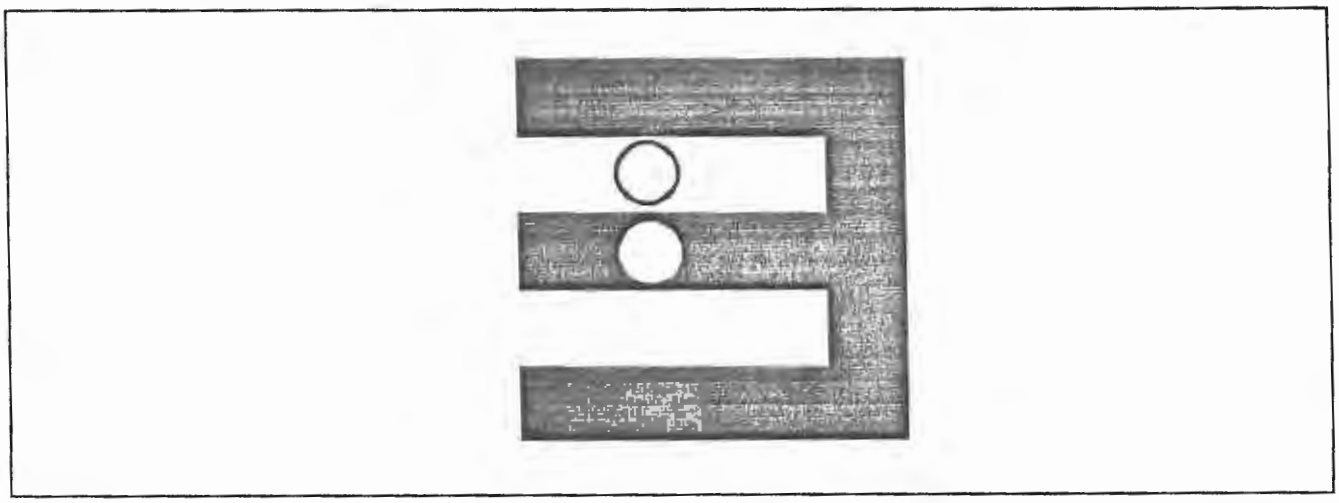


Diagram of the Aperture Through Which the Subject Viewed the Baylor Visual Acuity Tester Screen. (The circles represent the locations on the screen which were measured when the contrast was calculated. A 20/200 optotype was centered on the screen when the measurements were taken.)

APPENDIX B

Example Optotypes

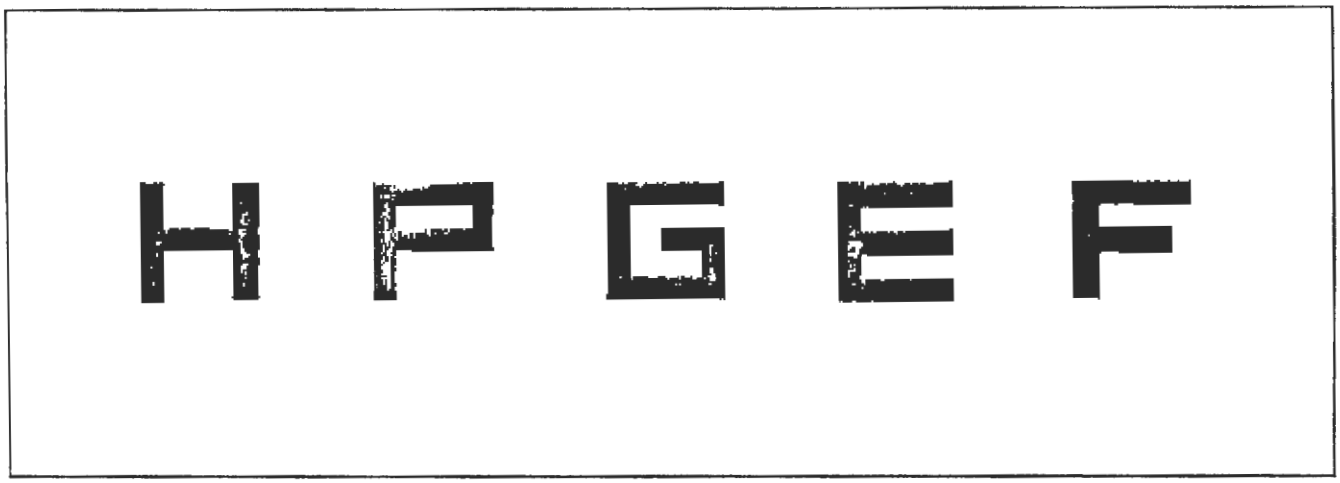
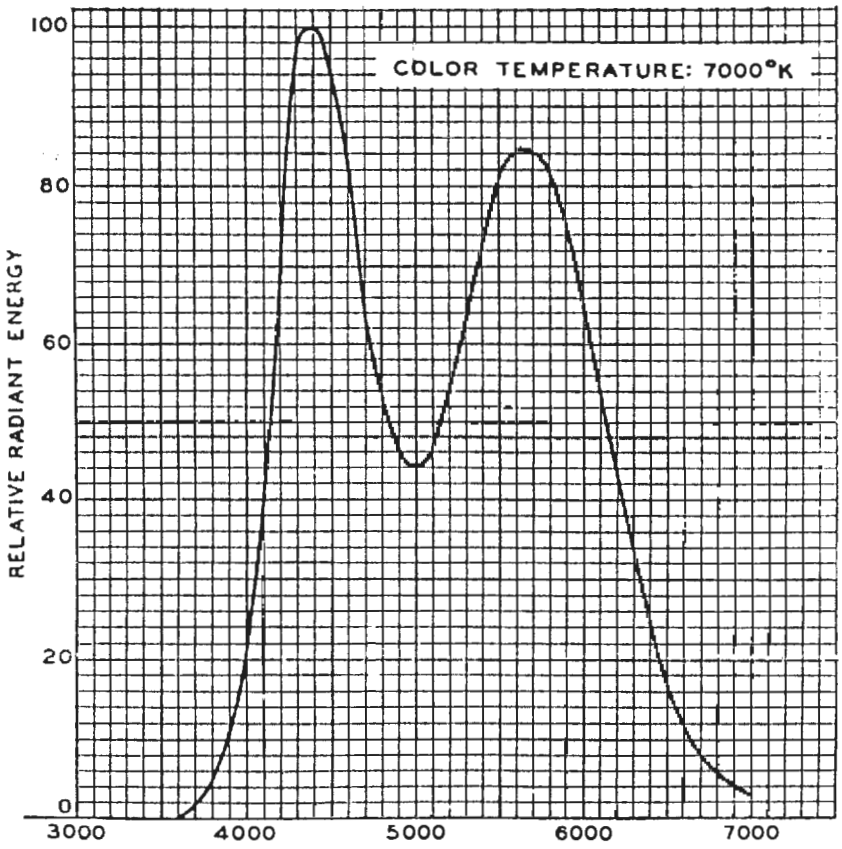


Diagram of the Aperture Through Which the Subject Viewed the Screen of the Baylor Visual Acuity Tester. (Five example optotypes are shown in the same way as they would be seen by the subject. At each presentation the optotypes were randomly changed by the BVAT microprocessor.)

APPENDIX C

Spectral Energy Characteristics of the P4 Phosphor



SPECTRAL ENERGY EMISSION CHARACTERISTICS of PHOSPHOR P4, SULFIDE TYPE. (From General Electric *Optical Engineering Handbook*, J.A. Mauro, Ed., 5th Printing, July 1963.)

APPENDIX D

Increase in Snellen Denominator and M.A.R. with Polycarbonate and CR39 Prism.

This table provides the data points upon which Figure 4 is based. It was derived from the mean M.A.R.'s which are found in APPENDIX E.

Condition		M.A.R.	M.A.R. Increase (from unaided)	Snellen VA (20/....)	Snellen Denominator Increase (From Unaided)
Unaided		0.66	-	-	-
Polycarbonate Prism	2	0.74	0.08	14.80	1.60
	4	0.81	0.15	16.20	3.00
	6	0.92	0.26	18.40	5.20
	8	1.05	0.39	21.00	7.80
	10	1.17	0.51	23.40	10.20
	12	1.31	0.65	26.20	13.00
	14	1.49	0.83	29.80	16.60
	16	1.56	0.90	31.20	18.00
CR39 Prism (p.d.)	2	0.68	0.02	13.60	0.40
	4	0.68	0.02	13.60	0.40
	6	0.70	0.04	14.00	0.80
	8	0.75	0.09	15.00	1.80
	10	0.82	0.16	16.40	3.20
	12	0.87	0.21	17.40	4.20
	14	0.95	0.29	19.00	5.80
	16	1.04	0.38	20.80	7.60

Increase in Snellen Denominator and M.A.R.
with Polycarbonate and CR39 Prism.

APPENDIX E

M.A.R. Scores

The scores in this table (Microsoft EXCEL) represent the mean M.A.R.'s for each subject for each testing condition. The 40 subjects are listed in column 1. Column 2 is the subject's unaided M.A.R. The remaining 16 columns are the subject's M.A.R.'s for each prism value on the polycarbonate scale and on the CR39 scale. As discussed in the Methods section, each M.A.R. entry is itself the mean of three visual acuity measurements which have been converted into minutes of arc.

M.A.R. Scores (EXCEL)

	UNAIDED	POLYCARBONATE								CR 39							
SUBJECT		P2	P4	P6	P8	P10	P12	P13.5	P15.5	C2	C4	C6.5	C8	C10	C12	C14.5	C16.5
1	0.79	0.92	0.88	0.96	1.00	1.38	1.17	1.38	1.65	0.79	0.79	0.83	0.88	0.88	0.88	1.00	1.13
2	0.71	0.88	0.96	0.88	0.96	1.33	1.50	1.42	1.58	0.79	0.79	0.71	0.75	0.96	0.96	0.79	1.00
3	0.58	0.71	0.79	0.96	0.88	1.08	1.04	1.08	1.38	0.58	0.67	0.63	0.67	0.67	0.71	0.63	0.67
4	0.58	0.75	0.71	0.71	1.04	1.00	1.25	1.29	1.42	0.63	0.50	0.63	0.58	0.63	0.79	0.79	0.83
5	0.58	0.63	0.63	0.71	1.08	1.04	1.33	1.38	1.67	0.63	0.63	0.63	0.71	0.63	1.00	0.96	0.83
6	0.63	0.58	0.71	0.75	0.75	0.88	0.96	1.04	1.29	0.58	0.67	0.58	0.67	0.71	0.79	0.75	0.83
7	0.63	0.58	0.67	0.63	0.75	1.17	1.46	1.46	1.54	0.54	0.63	0.63	0.54	0.75	0.58	0.75	0.79
8	0.63	0.63	0.67	0.63	0.71	1.04	1.25	1.21	1.38	0.54	0.67	0.58	0.63	0.63	0.63	0.79	0.79
9	0.67	0.75	0.79	0.92	1.00	1.13	1.29	1.46	1.54	0.67	0.71	0.79	0.75	0.88	0.92	0.96	1.00
10	0.79	0.88	0.83	0.92	1.08	1.25	1.38	1.54	1.63	0.71	0.75	0.79	0.96	1.00	1.00	1.04	1.17
11	0.63	0.67	1.21	1.08	1.38	1.79	1.83	2.25	2.42	0.58	0.63	0.71	0.67	0.75	1.00	1.13	1.50
12	0.63	0.67	0.71	0.88	0.96	0.96	1.29	1.29	1.17	0.67	0.58	0.54	0.71	0.83	0.83	0.79	1.00
13	0.58	0.75	0.96	0.88	1.25	1.46	1.63	1.63	1.96	0.71	0.58	0.67	0.88	0.75	1.25	1.13	1.17
14	0.75	0.92	0.83	1.04	1.17	1.13	1.29	1.25	2.00	0.79	0.71	0.75	1.00	0.92	0.79	1.08	0.92
15	0.88	1.08	1.08	1.63	1.58	1.96	1.79	1.79	2.00	0.79	0.71	0.88	1.04	1.04	1.21	1.21	1.71
16	0.63	0.71	0.79	0.79	1.00	0.88	1.17	1.63	1.33	0.58	0.54	0.63	0.67	0.83	0.75	0.75	1.08
17	0.71	0.92	1.08	1.54	1.75	1.63	2.13	1.88	1.79	0.83	0.67	0.75	0.88	0.83	1.04	1.25	1.25
18	0.88	1.00	1.13	1.50	1.92	1.75	2.04	2.08	1.83	1.04	0.92	1.00	1.25	1.71	1.63	1.71	1.79
19	0.42	0.63	0.79	0.88	0.88	1.08	1.00	1.50	1.21	0.54	0.54	0.58	0.71	0.63	0.71	0.79	0.83
20	0.50	0.50	0.54	0.63	0.75	0.83	1.04	1.04	1.17	0.46	0.46	0.50	0.54	0.63	0.63	0.71	0.71
21	0.92	0.88	0.96	1.00	1.13	1.00	1.29	1.58	1.58	0.92	0.96	0.96	0.92	0.96	0.92	1.04	1.29
22	0.58	0.75	0.71	0.88	1.25	1.50	1.67	1.46	1.50	0.63	0.63	0.63	0.67	0.79	0.88	0.92	1.13
23	0.58	0.79	0.79	0.83	0.88	1.00	1.17	1.54	1.33	0.63	0.67	0.67	0.75	0.88	0.79	0.83	0.83
24	0.63	0.63	0.67	0.75	0.83	1.00	1.21	1.63	1.46	0.63	0.67	0.71	0.63	0.75	0.79	1.04	0.96
25	0.63	0.67	0.75	0.88	0.88	0.96	1.08	1.21	1.21	0.67	0.75	0.67	0.71	0.58	0.79	0.96	0.83
26	0.83	0.88	1.00	1.29	1.25	1.17	1.42	1.92	1.88	0.88	0.83	0.79	0.92	1.21	0.92	1.08	1.29
27	0.67	0.75	0.71	0.88	0.83	1.13	1.17	1.33	1.42	0.67	0.75	0.79	0.71	0.75	0.88	0.79	0.79
28	0.58	0.63	0.75	0.75	0.88	0.88	0.96	1.42	1.63	0.63	0.63	0.71	0.67	0.79	0.71	0.92	0.92

29	0.50	0.67	0.83	1.04	1.08	1.21	1.33	2.08	1.83	0.63	0.67	0.75	0.71	0.71	0.96	0.96	1.25
30	0.54	0.63	0.63	0.79	0.83	0.83	1.08	1.08	1.17	0.58	0.63	0.63	0.63	0.79	0.83	0.83	0.88
31	0.67	0.75	0.88	0.83	1.13	0.92	1.17	1.29	1.38	0.75	0.63	0.63	0.67	0.75	0.96	0.88	0.96
32	0.67	0.71	0.75	0.79	0.96	0.83	1.00	1.21	1.17	0.71	0.67	0.71	0.71	0.75	0.75	0.79	0.83
33	0.71	1.08	0.96	0.96	1.21	1.58	1.58	1.67	2.04	0.88	0.79	0.92	0.75	0.88	0.88	1.08	1.42
34	0.63	0.71	0.79	0.92	0.88	1.04	1.33	1.71	1.46	0.63	0.67	0.58	0.71	0.79	0.79	0.92	1.25
35	0.71	0.79	0.92	1.00	1.04	1.33	1.25	1.58	1.71	0.79	0.79	0.79	1.00	0.92	0.88	1.08	1.00
36	0.63	0.75	0.83	0.83	1.33	1.25	1.38	2.17	1.96	0.71	0.75	0.75	0.83	1.04	1.08	1.08	1.29
37	0.88	0.71	0.79	1.00	1.13	1.33	1.29	1.25	1.54	0.67	0.71	0.58	0.71	0.75	0.92	1.04	0.96
38	0.58	0.63	0.71	0.75	0.88	1.04	0.92	1.21	1.42	0.58	0.67	0.58	0.79	0.79	0.88	0.92	0.88
39	0.54	0.54	0.58	0.63	0.79	0.88	0.75	1.04	1.13	0.54	0.50	0.54	0.54	0.58	0.50	0.67	0.67
40	0.54	0.67	0.67	0.88	1.04	1.25	1.33	1.54	1.63	0.63	0.54	0.63	0.54	0.75	0.71	1.04	1.29
MEAN	0.66	0.74	0.81	0.92	1.05	1.17	1.31	1.49	1.56	0.68	0.68	0.70	0.75	0.82	0.87	0.95	1.04
S.D.	0.11	0.14	0.15	0.23	0.26	0.28	0.29	0.32	0.30	0.12	0.11	0.12	0.15	0.20	0.20	0.20	0.27
	UNAIDED	P2	P4	P6	P8	P10	P12	P13.5	P15.5	C2	C4	C6.5	C8	C10	C12	C14.5	C16.5

APPENDIX F

Analysis of Variance Tables: Comparison of Mean Unaided M.A.R. to M.A.R.'s of All Polycarbonate "Treatments"

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	39	13.682	.351	2.736	.0001
Within subjects	320	41.025	.128		
treatments	8	33.982	4.248	188.187	.0001
residual	312	7.043	.023		
Total	359	54.707			

Reliability Estimates for- All treatments: .635 Single Treatment: .162

1

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Unaided	40	.655	.114	.018
P2	40	.744	.138	.022
P4	40	.811	.152	.024
P6	40	.915	.23	.036
P8	40	1.053	.265	.042

2

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
P10	40	1.173	.282	.045
P12	40	1.306	.294	.046
P14	40	1.488	.315	.05
P16	40	1.56	.297	.047

3

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Unaided vs. P2	-.089	.055*	.877	2.649
Unaided vs. P4	-.155	.055*	2.678*	4.629
Unaided vs. P6	-.26	.055*	7.458*	7.724
Unaided vs. P8	-.398	.055*	17.5*	11.832
Unaided vs. P10	-.517	.055*	29.604*	15.389

* Significant at 90%

4

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Unaided vs. P12	-.65	.055*	46.794*	19.348
Unaided vs. P14	-.832	.055*	76.76*	24.781
Unaided vs. P16	-.905	.055*	90.661*	26.931
P2 vs. P4	-.067	.055*	.49	1.979
P2 vs. P6	-.171	.055*	3.22*	5.075

* Significant at 90%

5

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P2 vs. P8	-.309	.055*	10.541*	9.183
P2 vs. P10	-.428	.055*	20.289*	12.74
P2 vs. P12	-.561	.055*	34.857*	16.699
P2 vs. P14	-.744	.055*	61.225*	22.131
P2 vs. P16	-.816	.055*	73.702*	24.282

* Significant at 90%

6

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P4 vs. P6	-.104	.055*	1.198	3.096
P4 vs. P8	-.242	.055*	6.486*	7.203
P4 vs. P10	-.362	.055*	14.474*	10.761
P4 vs. P12	-.495	.055*	27.083*	14.72
P4 vs. P14	-.677	.055*	50.762*	20.152

* Significant at 90%

7

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P4 vs. P16	-.749	.055*	62.175*	22.303
P6 vs. P8	-.138	.055*	2.109*	4.108
P6 vs. P10	-.258	.055*	7.344*	7.665
P6 vs. P12	-.391	.055*	16.889*	11.624
P6 vs. P14	-.573	.055*	36.364*	17.056

* Significant at 90%

8

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P6 vs. P16	-.645	.055*	46.113*	19.207
P8 vs. P10	-.12	.055*	1.582	3.557
P8 vs. P12	-.253	.055*	7.061*	7.516
P8 vs. P14	-.435	.055*	20.958*	12.948
P8 vs. P16	-.507	.055*	28.498*	15.099

* Significant at 90%

9

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P10 vs. P12	-.133	.055*	1.959*	3.959
P10 vs. P14	-.315	.055*	11.025*	9.391
P10 vs. P16	-.388	.055*	16.652*	11.542
P12 vs. P14	-.182	.055*	3.689*	5.432
P12 vs. P16	-.255	.055*	7.188*	7.583

* Significant at 90%

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P14 vs. P16	-.072	.055*	.578	2.151

* Significant at 90%

APPENDIX G

Analysis of Variance Tables: Comparison of Mean Unaided M.A.R. to M.A.R.'s of All CR39 "Treatments"

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	39	6.923	.178	6.057	.0001
Within subjects	320	9.378	.029		
treatments	8	5.992	.749	69.03	.0001
residual	312	3.385	.011		
Total	359	16.301			

Reliability Estimates for- All treatments: .835 Single Treatment: .36

1

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Unaided	40	.655	.114	.018
C2	40	.68	.121	.019
C4	40	.676	.106	.017
C6	40	.696	.117	.018
C8	40	.751	.154	.024

2

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
C10	40	.822	.199	.031
C12	40	.873	.197	.031
C14	40	.947	.196	.031
C16	40	1.043	.267	.042

3

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Unaided vs. C2	-.025	.038	.141	1.063
Unaided vs. C4	-.021	.038	.102	.902
Unaided vs. C6	-.04	.038*	.373	1.728
Unaided vs. C8	-.096	.038*	2.123*	4.121
Unaided vs. C10	-.166	.038*	6.368*	7.137

* Significant at 90%

4

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Unaided vs. C12	-.217	.038*	10.899*	9.338
Unaided vs. C14	-.292	.038*	19.577*	12.515
Unaided vs. C16	-.388	.038*	34.595*	16.636
C2 vs. C4	.004	.038	.003	.161
C2 vs. C6	-.016	.038	.055	.665

* Significant at 90%

5

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C2 vs. C8	-.071	.038*	1.17	3.059
C2 vs. C10	-.142	.038*	4.613*	6.075
C2 vs. C12	-.193	.038*	8.56*	8.275
C2 vs. C14	-.267	.038*	16.394*	11.452
C2 vs. C16	-.363	.038*	30.317*	15.574

* Significant at 90%

6

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C4 vs. C6	-.019	.038	.085	.826
C4 vs. C8	-.075	.038*	1.296	3.22
C4 vs. C10	-.145	.038*	4.861*	6.236
C4 vs. C12	-.196	.038*	8.896*	8.436
C4 vs. C14	-.271	.038*	16.858*	11.613

* Significant at 90%

7

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C4 vs. C16	-.367	.038*	30.947*	15.735
C6 vs. C8	-.056	.038*	.716	2.393
C6 vs. C10	-.126	.038*	3.658*	5.409
C6 vs. C12	-.177	.038*	7.238*	7.61
C6 vs. C14	-.251	.038*	14.544*	10.787

* Significant at 90%

8

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C6 vs. C16	-.347	.038*	27.782*	14.908
C8 vs. C10	-.07	.038*	1.137	3.016
C8 vs. C12	-.121	.038*	3.401*	5.216
C8 vs. C14	-.196	.038*	8.806*	8.393
C8 vs. C16	-.292	.038*	19.577*	12.515

* Significant at 90%

9

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C10 vs. C12	-.051	.038*	.605	2.2
C10 vs. C14	-.125	.038*	3.614*	5.377
C10 vs. C16	-.221	.038*	11.278*	9.499
C12 vs. C14	-.074	.038*	1.262	3.177
C12 vs. C16	-.17	.038*	6.658*	7.298

* Significant at 90%

One Factor ANOVA-Repeated Measures for X_1 ... X_9

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
C14 vs. C16	-.096	.038*	2.123*	4.121

* Significant at 90%

APPENDIX H

Analysis of Variance Tables: Comparison of Differences Between All CR39 and Polycarbonate "Treatments"

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	39	4.308	.11	1.977	.0009
Within subjects	280	15.648	.056		
treatments	7	8.466	1.209	45.98	.0001
residual	273	7.181	.026		
Total	319	19.956			

Reliability Estimates for- All treatments: .494 Single Treatment: .109

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
P2-C2	40	.064	.07	.011
P4-C4	40	.134	.128	.02
P6-C6	40	.219	.179	.028
P8-C8	40	.302	.192	.03
P10-C10	40	.351	.253	.04

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
P12-C12	40	.433	.207	.033
P14-C14	40	.541	.232	.037
P16-C16	40	.517	.21	.033

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P2-C2 vs. P4-C4	-.07	.06*	.536	1.937
P2-C2 vs. P6-C6	-.155	.06*	2.61*	4.274
P2-C2 vs. P8-C8	-.237	.06*	6.114*	6.542
P2-C2 vs. P10-C10	-.287	.06*	8.916*	7.9
P2-C2 vs. P12-C12	-.368	.06*	14.729*	10.154

* Significant at 90%

4

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P2-C2 vs. P14-C14	-.477	.06*	24.688*	13.146
P2-C2 vs. P16-C16	-.453	.06*	22.289*	12.491
P4-C4 vs. P6-C6	-.085	.06*	.78	2.337
P4-C4 vs. P8-C8	-.167	.06*	3.029*	4.605
P4-C4 vs. P10-C10	-.216	.06*	5.079*	5.963

* Significant at 90%

5

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P4-C4 vs. P12-C12	-.298	.06*	9.646*	8.217
P4-C4 vs. P14-C14	-.407	.06*	17.948*	11.209
P4-C4 vs. P16-C16	-.383	.06*	15.912*	10.554
P6-C6 vs. P8-C8	-.082	.06*	.735	2.268
P6-C6 vs. P10-C10	-.132	.06*	1.878*	3.626

* Significant at 90%

6

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P6-C6 vs. P12-C12	-.213	.06*	4.939*	5.88
P6-C6 vs. P14-C14	-.322	.06*	11.244*	8.872
P6-C6 vs. P16-C16	-.298	.06*	9.646*	8.217
P8-C8 vs. P10-C10	-.049	.06	.263	1.358
P8-C8 vs. P12-C12	-.131	.06*	1.864*	3.612

* Significant at 90%

7

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P8-C8 vs. P14-C14	-.239	.06*	6.23*	6.604
P8-C8 vs. P16-C16	-.216	.06*	5.056*	5.949
P10-C10 vs. P12-C12	-.082	.06*	.726	2.254
P10-C10 vs. P14-C14	-.19	.06*	3.931*	5.246
P10-C10 vs. P16-C16	-.166	.06*	3.011*	4.591

* Significant at 90%

8

One Factor ANOVA-Repeated Measures for X_1 ... X_8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
P12-C12 vs. P14-C14	-.108	.06*	1.279	2.992
P12-C12 vs. P16-C16	-.085	.06*	.78	2.337
P14-C14 vs. P16-C16	.024	.06	.061	.655

* Significant at 90%

9

APPENDIX I

Statement of Informed Consent

A statement of informed consent was completed by each subject in this study. The statements are on file with the Assistant Dean, College of Optometry, Pacific University.

Statement of Informed Consent

1. Title of Project: Image Quality as a Function of Induced Dispersion With Polycarbonate and CR39 Lenses.

2. Principal Investigator: Lawrence D. Hampton, O.D., 357-3199.

3. Faculty Advisor: Niles Roth, M.Opt., Ph.D., 357-7598

4. Location: Pacific University College of Optometry, Forest Grove, OR

5. Date: Summer, 1989

6. Description of Project. You have been asked to participate in a study which will assess the clarity of vision through certain types of spectacle lens materials. I will be measuring your distance visual acuity unaided and through each of sixteen lenses. The lenses, in the form of prisms, will be placed in a trial frame which you will wear during the testing.

The measurement of visual acuity will consist of this: You will sit in a chair and view a video monitor placed several feet away. On the screen you will see standard acuity chart letters which you will be asked to read. Letters of varying sizes will be shown to you to determine your visual acuity.

The testing will be performed one eye at a time. For each eye, then, testing will include seventeen measurements of visual acuity. If both your eyes have 20/20 or better unaided distance visual acuity, both eyes will be tested. If not, only the 20/20 eye will be tested.

It is estimated that the entire sequence will require thirty minutes per eye. Each participant will be involved in one session only.

This study is part of a master's thesis project which will also be submitted for publication in an optometric journal. The findings will be used to predict the clarity of vision which can be achieved with the different lens materials, information which will be of use to practicing optometrists.

7. Description of Risks. There are no foreseeable risks to subjects. Customary care will be observed with the trial frame and lenses so that you are not exposed to sharp corners or rough handling near the face.

The laboratory will be kept orderly and the room lights will on at all times.

It is expected that your vision will be blurred or distorted by some of the lenses. In the extreme case this may cause you to become uneasy or uncomfortable during testing. If this occurs, I

encourage you to let me know so that we can interrupt the testing for your comfort. Interrupting will not invalidate the findings. If necessary testing can be rescheduled or discontinued entirely.

Even in the absence of discomfort, the testing sequence may be fatiguing due to its length.

It is not expected that you will incur any costs as result of your participation in this study, except for transportation to and from the College of Optometry.

8. Benefits to Subjects. Though you will not be paid for your participation in this study, I do offer my sincere personal thanks for your help. The information gained will provide eye care practitioners with the knowledge necessary to advise their patients in the selection of the best lens material for their needs.

9. Withdrawal. Your participation in this study is wholly voluntary. If you decline to participate or ask to withdraw, it will involve no penalty to you or loss of any benefits to which you are otherwise entitled. You may withdraw at any time merely by notifying me of your wishes. Similarly, I reserve the privelege of cancelling your participation if I decide it is necessary, and in such case there is no penalty to you whatever.

10. Number of Subjects. Twenty or more subjects have been recruited for this study, for a total of forty eyes with 20/20 or better visual acuity.

11. Confidentiality. Your visual acuity findings will be filed under your name until all data have been gathered. During and after the analysis of data only your initials will be used. At no time will your results be discussed or released under your name without your personal consent.

12. Compensation and Medical Care. If you are injured in this experiment it is possible that you will not receive compensation or medical care from Pacific University, myself, or any organization associated with the experiment. All responsible care, however, will be used to prevent injury.

13. Offer to Answer Inquiries. If at any time you have questions of any sort about the study or your participation in it, please ask me. If you are not satisfied with the answers you receive, please call Dr. Roth or Dr. James Peterson at 357-0442. Participation in this study does not make you a patient of the Pacific University College of Optometry Clinic, and all inquiries should be directed to me or to my faculty advisor, Dr. Roth.

I have read and understand the above. I am 18 years of age or over (or this form is signed for me by my parent or guardian).

Printed name _____

Signature_____Date_____

Address_____Phone_____

City _____ State /Zip _____

Name and address of a person not living with you who will always know your address:

_____

_____

APPENDIX J

IRB Submission

Prior to initiating the study it was necessary to submit this paper to the local area Institutional Review Board. Their review and approval of the protocol is a requirement of all studies which make use of human subjects.

IRB Submission
Lawrence D. Hampton, O.D.

I. Project title.

Image Quality as a Function of Induced Dispersion with Polycarbonate and CR39 Lenses.

II. Abstract.

Polycarbonate is an extremely strong plastic which is commonly used for face shields and helmets. It is increasingly recommended as the material of choice in prescription and nonprescription safety glasses, and it is being used in street-wear spectacles as well. A drawback of the material, however, is its high dispersion. This is the characteristic which causes prisms to separate light into its component colors. It causes color fringes and blur in the periphery of prescription lenses, in increasing degree with stronger lens powers due to their greater prismatic effect. The dispersion characteristics of polycarbonate are twice that of glass and of the most commonly used spectacle lens material, CR39 plastic.

Although this trait of polycarbonate is widely known, the blur that it causes has not been adequately measured. In this study I will measure the loss of optical clarity caused by prisms of polycarbonate and of CR39. It will then be possible to predict the blur which will result when given lens powers in those materials are prescribed.

III. Location of project.

The study will be conducted in laboratory facilities in the Pacific University College of Optometry.

IV. Project Overview.

The study consists of measuring subjects' visual acuity through polycarbonate and CR39 prisms.

Twenty or more subjects will be selected from Pacific University faculty, staff, students, and family members. The subjects will be selected based on their having 20/20 or better uncorrected distance visual acuity. (The total number of eyes to be tested is 40; if some subjects have the required unaided visual acuity in one eye only, additional subjects will be recruited in order to achieve that total.)

Eight prisms each of polycarbonate and of CR39 are being fabricated. Each group of eight prisms comprises a series of increasing powers, from 2 prism diopters through 16 prism diopters. The prisms are being cut and edged in the same way as spectacle lenses and are being mounted in metal trial lens rings.

Subjects will be seated wearing a trial spectacle frame. The unaided visual acuity of each eye will be measured using the Baylor Visual Acuity Tester (BVAT), a video display terminal controlled by a microprocessor. A "staircase" (bracketing) technique will be used for measuring the visual acuity. Each of the sixteen prisms will then be placed in the trial frame before the tested eye and the visual acuity through each will be measured in the same manner.

V. Risks.

There are no expected risks to the subjects. No procedures which can be considered invasive are to be performed, and the subjects' eyes are not to be touched.

Trial spectacle frames will be placed before the subjects' eyes, and the tested prisms will be inserted and removed while the frame is in place. During that sequence, untoward events such as bumping the nose or the eye are conceivable but are not

expected. The frame and the prisms will be carefully handled, and those precautions should prevent such accidents.

Since the vision through many of the prisms is expected to be distorted to some degree, there is the possibility that subjects will become uneasy and, in the extreme case, nauseated. Breaks from testing, cool compresses, rescheduling, and discontinuation of testing if necessary will be provided for the subjects' comfort.

The testing sequence may become protracted and taxing, resulting in fatigue.

There will be the normal concerns for safety in traveling to the building, walking through the halls, and passing in and out of the laboratory. The laboratory will be kept orderly to minimize that risk, and the room light will be turned up while subjects are passing in and out.

VI. Monitoring procedures.

Clear instructions will be provided to the subjects prior to testing. Particular emphasis will be placed on discomfort and fatigue, and subjects will be encouraged to interrupt testing if they become uncomfortable.

An informed consent form will be read and signed by each subject prior to testing, and opportunity for questions will be provided.

I will be performing all testing, and during testing I will be continually monitoring the subjects for any evidence of discomfort.

Any subject who complains of dizziness or nausea will be encouraged not to drive until feeling normal. The day after testing I will telephone any subjects who have any adverse responses, in order to confirm that they have returned to normal and have had no recurrences of discomfort.

VII. Sample of Informed Consent Form.

1. Title of Project: Image Quality as a Function of Induced Dispersion With Polycarbonate and CR39 Lenses.
2. Principle Investigator: Lawrence D. Hampton, O.D., 357-3199
3. Faculty Advisor: Niles Roth, M.Opt., Ph.D., 357-7598
4. Location: Pacific University College of Optometry, Forest Frove, OR
5. Date: Summer, 1989
6. Description of Project. You have been asked to participate in a study which will assess the clarity of vision through certain types of spectacle lens materials. I will be measuring your distance visual acuity unaided and through each of sixteen lenses. The lenses, in the form of prisms, will be placed in a trial frame which you will wear during the testing.

The measurement of visual acuity will consist of this: You will sit in a chair and view a video display terminal placed several feet away. On the screen you will see an upper case letter E, but it will not necessarily be upright. I will ask you to tell me if the limbs of the letter point toward the right, the left, up, or down. Letters of varying sizes will be shown to you to determine your visual acuity.

The testing will be performed one eye at a time. For each eye, then, testing will include seventeen measurements of visual acuity. If both your eyes have 20\20 or better unaided distance visual acuity, both eyes will be tested. If not, only the 20/20 eye will be tested.

It is estimated that the entire sequence will require thirty minutes per eye. Each participant will be involved in one session only.

This study is part of a master's thesis project which will also be submitted for publication in an optometric journal. The findings will be used to predict the clarity of vision which can be achieved with the different lens materials, information which will be of use to practicing optometrists.

7. Description of Risks. There are no foreseeable risks to subjects. Customary care will be observed with the trial frame and lenses so that you are not exposed to sharp corners or rough handling near the face.

The laboratory will be kept orderly and the room lights will be turned up at all times.

It is expected that your vision will be blurred or distorted by some of the lenses. In the extreme case this may cause you to become uneasy or uncomfortable during testing. If this occurs, I encourage you to let me know so that we can interrupt the testing for your comfort. Interrupting will not invalidate the findings. If necessary testing can be rescheduled or discontinued entirely.

Even in the absence of discomfort, the testing sequence may be fatiguing due to its length.

It is not expected that you will incur any costs as result of your participation in this study, except for transportation to and from the College of Optometry.

8. Benefits to Subjects. Though you will not be paid for your participation in this study, I do offer my sincere personal thanks for your help. The information gained will provide eye care practitioners with tne knowledge necessary to advise their patients in the selection of the best lens material for their needs.

9. Withdrawal. Your participation in this study is wholly voluntary. If you decline to participate or ask to withdraw, it will involve no penalty to you or loss of any benefits to which you are otherwise entitled. You may withdraw at any time merely by notifying me of your wishes. Similarly, I reserve the privelege of cancelling your participation if I decide it is necessary, and in such case there is no penalty to you whatever.

10. Number of Subjects. Twenty or more subjects have been recruited for this study, for a total of forty eyes with 20/20 or better visual acuity.

11. Confidentiality. Your visual acuity findings will be filed under your name until all data have been gathered. During and after the analysis of data only your initials will be used. At no time will your results be discussed or released under your name without your personal consent.

12. Compensation and Medical Care. If you are injured in this experiment it is possible that you will not receive compensation or medical care from Pacific University, myself, or any organization associated with the experiment. All responsible care, however, will be used to prevent injury.

13. Offer to Answer Inquiries. If at any time you have questions of any sort about the study or your participation in it, please ask me. If you are not satisfied with the answers you receive, please call Dr. Roth or Dr. James Peterson at 357-0442. Participation in this study does not make you a patient of the Pacific University College of Optometry Clinic, and all inquiries should be directed to me or to my faculty advisor, Dr. Roth.

I have read and understand the above. I am 18 years of age or over (or this form is signed for me by my parent or guardian).

Printed name_____

Signature _____

Date _____

Address_____Phone _____

City _____State /Zip_____

Name and address of a person not living with you who will always know your address _____

_____

VIII. Dates of Project. All data collection requiring participation of subjects will be conducted between 1 June 1989 and 1 September 1989.

IX. Principal Investigator: Lawrence D. Hampton, O.D.

_____

Faculty Advisor: Niles Roth M.Opt., Ph.D.

_____

APPENDIX K

Instructions to Subject

These instructions were read to each subject prior to testing, in order to standardize the information provided to each.

Instructions to Subject

I will show you a row of five letters. They may be clear or blurry, large or small. Your task is to read them as best you can. You will have eight seconds; after that the screen will go blank.

Here is an example. Take note of how long eight seconds lasts. (Show 20/40 example.) Here's another. (Show 20/25 example.) Note that the eight seconds is plenty of time if the letters are easy to read, but that it may press you a little if they are small or blurry. (Show 20/15 example.)

Please try your best, and it's all right to guess. If you can't read the letters, I'll increase their size until you can. If you can read them, I'll reduce their size until you can't.

It's perfectly all right to correct yourself or change your mind within the eight seconds.

Please don't squint, and be sure to hold your head straight; don't tilt or turn your head to achieve better vision.

We will do this several times with the naked eye and through each of the prisms.

Do you have any questions? Be sure to interrupt any time if you do, or if you want to take a break or adjust your position or the trial frame.

Then let's begin.

APPENDIX L

Data Collection Protocol

Data Collection Protocol

1. Subject (S) is asked to arrive fifteen minutes before the scheduled time of testing. S sits at a desk in the hallway and reviews and signs the Informed Consent Form. When that is completed, Experimeter (E) retrieves the signed consent form and offers the opportunity to ask questions. E explains that the instructions will be repeated at the beginning of the testing sequence, and at that time another opportunity to ask questions will be presented.

2. S is seated in the examining chair. The trial frame is placed on the subject and adjusted for comfort and proper alignment, to include approximately ten degrees of pantoscopic tilt. E places an occluder in the trial frame before the non-tested eye. If both of S's eyes are to be tested, the right eye is tested first (the left eye is covered first.) The room lights over S and E are left on during testing.

3. E reads the instructions to S and demonstrates the testing method. Final questions are answered.

4. E measures S's unaided monocular visual acuity (see Testing Method). Using the preprinted data sheets, E enters the Snellen denominator for each end point.

5. The prisms are then placed one at a time in the trial frame, in no particular sequence, and the procedure described in paragraph 4 is followed for each. The prisms are oriented obliquely (base apex line @ 45 OD, @135 OS) so that the prisms are not aligned with the predominant horizontal and vertical elements of the stimulus optotypes.

6. If the other eye is to be tested, the occluder is reversed and paragraphs 4 and 5 are repeated.

7. S is reminded during testing that he/she should request a break if desired for fatigue or discomfort.

8. At the conclusion of testing, E thanks S and escorts S to the door. E reminds S that there may be some eye fatigue but that it should go away within a few hours. S is asked to notify E if it does not.

APPENDIX M

Testing Procedure

Testing Procedure

I. Definitions and Parameters

1. Subject (S) is shown a row of five letters per trial. Four or five correct (at least 80% correct) is a *correct* response. Less than four is an *incorrect* response.

2. When the optotype size exceeds 20/42.5, the BVAT automatically reduces the number of letters per row to three. In this case, two or three of the three letters must be read for a *correct* response (at least 66.6% correct).

3. S is given eight seconds per trial, and may make changes as desired within that period.

4. A *run* is a series of trials which concludes in an end point. The number of trials in a run is not fixed; at the minimum it consists of one *correct* response paired with one *incorrect* response one step smaller.

5. The end point of a run occurs when S gives an *incorrect* response which follows one or more *correct* responses, or gives a *correct* response following one or more *incorrect* responses.

6. The visual acuity indicated by a run is the smallest letter size for which a *correct* response is given. The Snellen denominator for this acuity level is recorded.

5. There are three runs per testing condition. Testing includes seventeen conditions per eye (sixteen prisms plus the naked eye).

6. Each time the letter size is changed, the letters are changed.

7. S is asked to close the eyes when prisms are being changed.

II. Psychophysical Technique

1. Start each set of three runs with a letter size expected to be above threshold.

2. If the response to the first trial (or any subsequent trial) is *correct*, reduce the stimulus size one step and change the letters. Repeat until an *incorrect* response results. This ends the run.

3. If the response to the first trial (or any subsequent trial) is *incorrect*, change the letters and present the next larger size. Repeat until a *correct* response results. This ends the run.

4. This is an adaptation of the method of limits. The stopping point (optotype size) of the first run becomes the starting point of the second run. The stopping point of the second run becomes the starting point of the third run. This means the first run starts above threshold, the second run begins below the threshold determined by the first run, and the third run starts at or above the threshold indicated by the second run. (If the results of the three runs are not the same, which is common, then the averaged threshold may not be bracketed in exactly that manner. The procedure, however, is standardized as described.)

APPENDIX N

Sample Data Form

This form was utilized in recording the raw data. The Snellen visual acuity denominator at the end point of each run was recorded by the experimenter. Those data points were then entered onto the same form in a spreadsheet program which calculated the M.A.R. equivalent for each entry. The program also calculated the mean M.A.R. for each subject for each testing condition, or "treatment". That number was transferred onto the spreadsheet in APPENDIX E, which calculated mean M.A.R.'s for the entire population of 40 eyes.

Data Form (BVAT)

Subject:		Age:		OD / OS		F / M											
						POLYCARBONATE											
	0	a	P2	a	P4	a	P6	a	P8	a	P10	a	P12	a	P13.5	a	P15.5	a
Trial no.1		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
2		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
3		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
avg. a	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00
						CR 39												
			C2	a	C4	a	C6.5	a	C8	a	C10	a	C12	a	C14.5	a	C16.5	a
Trial no.1	***	***		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
2	***	***		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
3	***	***		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
avg. a	***	***	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00	***	0.00

APPENDIX O

Data

The raw data is filed with the Assistant Dean, College of Optometry, Pacific University.